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Concluding remarks

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Sitting in the audience there, I have enjoyed the last four days of the meeting. Now that I am here on the podium to summarise the seminar, the view of the world is not exactly the same. I am reminded of a story of a zoo in a small town. The managers bought a young lion and put him in the zoo in the same cage as the old lion. The young fellow went about its job of roaring and entertaining children and visitors alike. All the time the old lion was sleeping, doing nothing. Then came the lunch time. The cook served a big fat piece of meat to the old lion and a few peanuts to the young one. The young lion could not stand the injustice any more. "Ha, you just sit there and do nothing and you get a fat piece of meat. I have been diligently working the whole morning and all I get for lunch are a few peanuts. How ungrateful is this world!" At that the older lion said, "Look here, my dear fellow. This is a small town. What they really needed was a monkey and they could not find one and hence they bought you. You better know it and get to working".

I, therefore, better get to working with all the humility. And summarize the meeting, I shall.

In his opening remarks, Prof. Warke outlined the scope of the Seminar and appropriately defined the aim of heavy ion collision studies.

(a) To discover all the isotopes upto neutron and proton drip lines for all the known elements.

(b) To measure masses, study the decay modes and life times and

(c) To carry out their spectroscopic studies.

For populating nuclei far off beta stability line, one needs higher beam energies, since these are endothermic reactions. At such energies, the number of open channels is large and hence the cross sections for producing these nuclei are small (< 1% of the total cross section). Therefore, such measurements require special channel selectors and detection techniques.

This is where the use of recoil mass separators [HERA at the NSC and the SHRI, under fabrication at Bombay] prove very useful. Detection of masses of nuclei alongwith gamma coincidences and other filters to define the channel enables one to detect such channels with low cross section. In fact such facilities could be effectively used for studying a number of problems. To list a few :

(a) Study of isomers in 0.3 millisec–3 microsec range would become now feasible.

(b) Nuclei far off beta-stability—the spectroscopic studies have revealed new magic numbers corresponding to $A = 100$ ($N = Z = 50$), $A = 132$ ($Z = 50$, $N = 82$) in the spherical region and $Z = 38$, $N = 38$ in the deformed region. Long standing predictions exist that new magic numbers must exist particularly when there is reinforcement of proton and neutron gaps for the same deformation. This reinforcement occurs over narrow range around proton and neutron shell gaps and leads to superdeformed ground states with deformation as high as 0.4. Spectroscopic studies of such nuclei need to be taken up.

(c) Production of Radioactive beams : Nuclear reactions with large cross sections such as $^{12}C(^{116}Sn, 4n)$ lead to hitherto unavailable radioactive beams of ^{124}Ba albeit with small intensity.

Experiments to determine lifetimes of levels in the compound nucleus were reported by Ms. Vandana. Using two dimensional position sensitive detector, measurements at the Bombay pelletron were carried out to determine the life times in the range 10^{-17}–10^{-19} sec. by the " blocking method".

The dissipation of energy and angular momentum in heavy ion induced reactions is generally understood to proceed by emission of a number of nucleons. The interaction responsible for the transfer of nucleons may be of "direct" type : includes those aspects of nuclear motion which are concerned with ordered motion as in *e.g.* single particle motion, collective excitation of the vibration type *etc.* On the other hand, a fused system could form and depending on the mass asymmetry a number of nucleons would evaporate following statistical decay of such a fused system. Thus both the direct interaction and compound nucleus are facts of life and one has learned to live with both. To separate the two clearly, has been difficult.

One may however, talk of typical examples representing these reaction mechanisms.

Typical examples of direct interaction are elastic and inelastic scattering, stripping / pickup of one nucleon and multinucleon transfer. In case of light ion induced reactions such as (d, ^{3}He) and (e e′p), one can obtain reliable structure information. Prof N G Puttaswamy even went a step ahead to talk of determination of *rms* radius for specific orbital as determined from (e e′p) reactions and making it a constraint to arrive at the bound state radius parameter in (d, ^{3}He) reaction. Dr. Subinit Roy presented analysis of inelastic scattering of light composite particles.

On the other hand, typical reactions involving compound nuclear formation are the fusion reactions, resulting in highly excited nuclei after a few nucleons evaporate and then decay by EM interaction.

Dr. S Saha presented fusion cross section measurements performed at the Bombay Pelletron using Bragg Curve spectrometer. He demonstrated on the basis of semiclassical trajectory calculations the necessity to include transfer channels in understanding the so called enhancement of fusion cross section over the predictions of one dimensional barrier penetration model. The results clearly indicated the influence of direct interactions in explaining the behaviour of fusion cross section.

Taking stock of charged particle spectroscopy, which includes study of elastic, inelastic, transfer and fusion channels, Dr. S Datta mentioned about the various anomalies–threshold anomaly in the elastic scattering at energies close to Coulomb energy,-anomalous reorientation in the inelastic scattering, slope anomaly in transfer probabilities of one and multiparticle transfer reactions and the enhancement in the 2*N*-transfer channels.

The observation of a marked energy dependence in low energy heavy ion elastic scattering has been an important development. It has been found that the real part of the nuclear optical potential increases in strength and almost doubles as the bombarding energy is lowered towards the barrier while the corresponding imaginary potential decreases abruptly. This correlation is to be understood in general term by a dispersion relation. The polarization potential is caused by coupling the elastic channel to other reaction channels. Dr. Datta referred to the anomalous reorientation effects seen in inelastic scattering of ^{28}Si + ^{28}Si (2+). Studies were performed at the NSC and presented by Prof. Tiwari.

Results on the slope anomaly in the transfer probabilities of single and multi nucleon transfer were presented by Mr. B J Roy and Dr. S Saha in two separate experiments carried out at the Bombay Pelletron.

In the papers presented by Mr. B J Roy on (^{12}C, X) studies on ^{88}Sr nucleus, he proceeded first to examine the extent to which single proton transfer data is understandable in terms of DWBA. Previous light ion induced single particle transfer data helps in understanding the heavy ion data better. Having so concluded he proceeded to obtain the transfer probability for a specific single particle transition from the data on ^{89}Y and then compare with a specific single particle transition for 2 proton transfer *i.e.* the ground state transition in ^{90}Zr. Three results came out of these studies.

i) The slopes of $P_{1p}(d_0)$ and $P_{2p}(d_0)$ are different.

ii) In terms of absolute value, the transfer probability for transferring a pair of $[2p_{3/2}]^2$ is about 300 times more than transferring two protons sequentially *i.e.*

$$\frac{[P_{2p}]}{[P_{1p}]} = 300 \quad (\text{at } d_0 = 1.72 \text{ fm}^{-1})$$

thus reflecting the importance of pairing interaction.

iii) Instead of using the cross section for a specific *g.s.* transition in ^{90}Zr, if one takes the energy integrated (over say, 5 MeV excitation range) cross section for computing the transfer probability P_{2p}, the slopes obtained for the two cases are different. Moreover calculation of enhancement factor becomes difficult in the absence of knowledge of distribution of single particle strength over the excitation range of 5 MeV.

Efforts to understand HI elastic scattering in terms of simplified microscopic method that accounts for essential feature of resonating group method and generator coordinate method in good approximation were reported by Dr. Ashok Kumar. The threshold anomaly and the anomalous large angle scattering have been explained. Dr. Ramdev Raj presented the folded Yukawa Interaction potential model for the description of HI elastic scattering. The fact that the predictions are as good as the standard W–S form only indicates the importance of strong absorption and hence the grazing impact parameter in HI elastic scattering.

As mentioned by Prof. Warke, one of the main push towards obtaining nuclear structure information came from the study of changes of shapes from nucleus to nucleus. The understanding of these properties has been done in terms of different macroscopic models by treating the nucleus as a crystal, a liquid drop, a rotating top, a Fermi gas *etc*. The observation of superdeformed states constitutes an important confirmation of the shell structure of the nucleus. Connection between the various models in terms of some universal microscopic theory has proceeded along two lines. (a) Deformed shell model with configuration mixing. (b) The interacting Boson model. Prof Pandya outlined the methodology of deformed shell model calculations and showed that a Hartree Fock calculation in a limited shell model configuration space generates a self consistent deformed shell model basis. Configuration mixing in this deformed shell model space provide a close approximation to standard spherical shell model calculation with large amount of configuration mixing and hence consequent enormous computational labour. Prof. Pandya's colleagues, Dr. Rath, Dr. Praharaj and Dr. Tripathi presented calculations for various nuclei and outcome are wonderful predictions.

Their pet formula —
Assume ^{56}Ni as core.

S P Energies for	$p^{3/2}$	$f^{5/2}$	$p^{1/2}$	$g^{9/2}$
[MeV]	0	0.7	1.08	3.7

MODIFIED KUO Interaction.

Abracadabra

One almost nostalgically remembers the period in the late' 60s when HF calculations were reported. Only difference now is that the calculations are being compared with data obtained within the country. As Prof. Pandya rightly and proudly pointed out — for once theoreticians and experimentalists are on the same wave length. As an experimentalist, I can appreciate how valuable it is to have a theory friend around who understands you. I remember, first time I attempted Nilsson model calculations in 1965, it took about 2 hours of discussion with a theory friend before he understood where I was getting stuck. The difficulty was solved in next 2 minutes.

Communication gap! How embarrassing it can be. All of You, as a child, must have heard about the story of Mungus and the child. If only the Mungus could communicate .....! It's death was wholly unnecessary.

The other microscopic approach, namely the *sdg*-interacting Boson model was outlined by Dr. Durga Devi. Two examples, namely the spectroscopic properties [spectra, $B(E2)$, $B(E4)$ *etc*] of the rotor-gamma unstable transitional Ds–Pt isotopes (ii) the analytical formulation of two nucleon transfer spectroscopic factors and the sum rule quantities were described in detail in terms of SDG IBM. Advantages of the model are a large number of analytical formulas which facilitate rapid analysis of the data and provide insight into the underlying structures in terms of dynamical symmetries in the model.

While we are on the subject of change of shapes from nucleus to nucleus, it is equally interesting to find out change of shape in the same nucleus as a function of excitation energy. It is well known that the resonance like structures of intermediate width are observed in the excitation function studies in several nucleus-nucleus collisions.

Several microscopic and schematic models have been suggested in the analysis of resonances — mainly centred around the idea of nuclear molecular resonance states.

* Iachello — modelled after rotational–vibrational spectra of atomic molecules.
* Cindro and Pocanic — studied the resonance state as due to interaction of two orbiting nuclei.
* Satpathy *et al* — used larger range Morse potentials to generate resonance states.
* Cindro and Greiner — used potential approach with an anharmonic potential well with a –ve quartic term.

Prof. C S Sastry presented another model in which the molecular resonances originate primarily from special features of total Nucleus–nucleus effective potential including Coulomb and the centrifugal terms in the surface region. The effective real nucleus-nucleus potential between two heavy ions is characterised by a Coulomb barrier region and a potential packet which gets shallower as l increases and the centrifugal barrier is closer to the origin. The resonances can originate in the potential pocket and on the top of the barrier provided the absorption is not too large in the barrier region and the barrier is reasonably flat. These are referred to in the literature as barrier top resonances and resonances associated with orbiting cluster model *etc.*

On the other hand, Dr. Eswaran, presented experimental evidence to infer that the resonances might be manifestations of shape isomeric states of compound system produced in superdeformed second well in the potential energy surface. In the excitation function of the reactions $^{12}C(^{16}O, ^{8}Be)^{20}Ne$ and $^{12}C(^{16}O, O)^{24}Mg$ leading to several states, the cross channel correlations of the resonances observed ($J_c = 14^+$) indicate preferential ^{8}Be decay of both the resonances to the $8p$-$4h$ states in ^{20}Ne — thus favouring an interpretation in terms of highly deformed shape isomeric configuration in ^{28}Si. Nilsson Strutinsky calculations confirm these resonances to be having structures corresponding to a secondary minimum with $e = 1.35$ and gamma = 60°.

How to go about doing cranked triaxial Nilsson model calculations to study excited s–d shell nuclei was presented by Prof. Shanmugam.

The seminar has been interesting and has brought out several problems worth pursuing with the Pelletrons. Having said that, I should like to draw your attention to some points raised by Prof. Warke.

1. Can we do it (research) ?
2. Do we have facilities and dedication ?

I believe I am entitled to my answers. As an experimentalist in this country, I am accustomed to being an optimist — nay, it has become my philosophy of life. In answer to these I should like to ask another question : Do we have choice ?

We have to do it.

We have the facilities and lastly, we have to have faith in the capacity of the younger lot sitting here and I am convinced they are capable of dedication, especially after enjoying this conference which they have organised with such a dedication. We must not give up.

Let me end my remarks with another of those stories. A barrister requested a judge for postponing hearing his case. On enquiry, he tells the judge that his wife is going to conceive and he would like to take some leave. The judge asked, "you mean she is about to deliver ?" The barrister insisted and repeated that his wife is about to conceive. His Lordship remarked, "My dear Fellow, I do not know what your wife wants to do. But

I am convinced that whatever she may do, your presence is necessary. Your request is granted".

If only we leaders are there on the spot, dedication from youngsters will be automatically forthcoming. We have to be there to do it (Research of course!).

On behalf of all the delegates, I should like to take this opportunity to thank Prof. N G Puttaswamy and his colleagues for the excellent organisation and the wonderful hospitality. I must also thank Prof. T V Ramkrishnan for ordering the right weather and thank God for accepting his order. Thank you.